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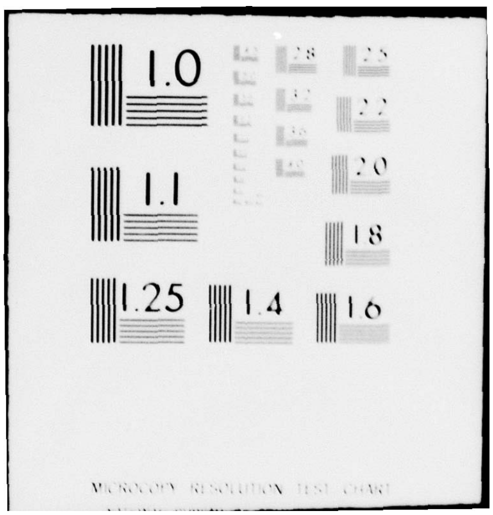
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

LIGHTGUIDES

by

Stefan Weinfeld

FOREIGN TECHNOLOGY DIVISION

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FTD -ID(RS)T-1973-77

EDITED TRANSLATION

FTD-ID(RS)T-1973-77 18 November 1977

MICROFICHE NR: FTD-77-C-001437

LIGHTGUIDES

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English pages: 10

Source: Mtody Technik, Vol. 26, No. 12, 1976, pp 43-47.

Country of origin: Poland
Translated by: SCITRAN
F33657-76-D-0390
Requester: FTD/ETDP
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FTD -ID(RS)T-1973-77 Date 18 Nov 1977

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LIGHTGUIDES

by

Stefan Weinfeld

The author of this article just forty years ago (yes!, he is indeed in quite advanced age) had an occasion to see the radio receiver, probably of an Austrian make, with the dial in the form of a map. Tuning in the given station, eg. Warsaw, was indicated by an illuminated point showing the location on a map. The design was probably patented, despite its simplicity: from the circumference of the drum around the dial there were outgoing glass rods bent in such a manner that each ending created a point indicating a city on a dial-map. The turning caused light bulb movement along the drum circumference and illuminating different rod endings, sort of injection of the light signal into them. Thus, due to the internal reflection phenomenon, the light was sent to the proper position on a dial.

Every glass rod was then a certain type of a light guide -- a primative one, but still a lightguide; the transmitted signal had the simplest imaginable structure, but it was a signal.

And so after a time period easily within a lifetime of one generation, thus not too long, the theory and the technology gave this most simple device status of almost a symbol of future telecommunication.(1) How did it happen? What is the genesis of a light guide? What is it today? What will it be tomorrow?

GENESIS

One of the tendencies in telecommunication almost from its inception is the increase of the bandwidth, ie. frequency region used for the signal transmission. Initially this tendency was dictated by economic reasons only,

(1) We ignore the application of fiber optics in medical instruments.

namely attempting to send over the already built telephone line, not one, but several and more telephone conversations. Later on, the technical reasons were added: one had to have such a transmission lines, over which the video signals could be sent, which took the band of much greater width than the Very High Frequency carrier. In the course of the telecommunication technology development, one could reach to higher and higher frequencies, but this necessitated the construction of new transmission lines.

Such a line for the radio waves of very high frequencies is among others, the wave guide, having a form of a metal pipe. It is well described by an AT&T flyer, content of which, according to the J. Martin book, "Future of the Telecommunication", I permit myself to quote:

"Two inch (50 mm diameter) empty pipe is able to transmit 230000 telephone conversations. The pipe is no thicker than your hand, but it is a fact, that inside there is absolutely nothing, except for the room for 230000 simultaneous telephone conversations. This pipe is able to transmit many more signals, not only the telephone conversations. It may also transmit the television programs and videophone signals. Electrocardiograms and the data between thousands of computers. All at once. . . "

In technology, just like in life, the application of given design is decided by economics: the returns must be justified by a need. But even before the beginning of wide use of waveguide lines, the work started on the competing means of transmission: the lightguides.

As the name indicates, the information carriers here are not the radio waves, but light (not necessarily visible, usually the infrared radiation). Although it may initially appear strange, the optical radiation has possibilities not worse than the radio waves. Both kinds of radiation have their place in the electromagnetic waves spectrum -- however, the light waves are much shorter than the shortest of the radio waves, and because of that, by a proper modulation, one may obtain a very

wide band. The attempts to build the light lines, analogous to the microwave radio lines, gave very good results, despite that these lines can be used only for very short distances (several kilometers, for example in the city between tall buildings). One has to take into account, that the bad atmospheric conditions, like rain or fog, also the air pollution or some temporary obstructions (like flying bird) make such communication difficult.

This is why one used the previous experience with the microwave waveguides and attempted to construct the similar lines for the optical radiation, equipped either with the optical lenses to focus the light beam or with the mirrors to keep the light rays propagating along the pipe. The real progress was made only after the glass threads suitable for light transmission were obtained, the kind we call today the light guides.

PRESENT DAY

The "light guides" which I mentioned at the beginning, were the rods a few milimeters in diameter. To describe the present day light guides I used the word "threads", although one should speak of the "glass hair" because of the very small light guide diameters. But let us agree, rejecting even the most descriptive names, to use the commonly accepted in the professional literature term, the "glass fiber".

The fibers used as the light guides differ in diameters, and at the same time in the transmission properties. The thing is, that although the light propagates inside the glass fiber according to well known laws of geometrical optics (it is worth mentioning here, that with those laws are connected the names of Dutch mathematician Willebrand Snell, who in 1621 formulated the rule relating the angle of incidence with the angle of refraction, and the French mathematician Peter Fermat who about 1650 established the so called principle of least time) but the precise mechanism of the light propagation in the fibers of very small diameters

can be explained in terms of wave theory, and with very complex mathematical apparatus. From those considerations, it follows that along the wave guide there may be propagated only certain well defined kind of waves called "modes". The optical fibers can propagate either only one mode and they are called "single mode", or several different modes, and in this case they are called "multimode ". In either case, "single mode" and "multimode " fibers have similar construction: the special glass core is surrounded by a glass envelope with lower refraction coefficient.

For the order, we have to add that there is another kind of fiber optics (developed by the Japanese) without the envelope: it is a fiber with radially varying refraction coefficient. The fiber is known as SELFOC (self-focusing) which well describes the properties of this light guide.

But as the French say, "let's go back to our sheep ". The multimode fibers are characterized by a core with a diameter of 50 to 100 μm, and the envelope diameter of 200 μm. The production of this fiber is relatively simple, so the price is rather low. Relatively large core diameter makes it easy to couple it to the light source. The disadvantage of the multimode fiber is the spreading of the narrow light pulse with the fiber length, which limits its information throughput. .

The single mode fiber core has a diameter of only 1 to 3 μm, or few light wavelengths. From the structural considerations (it is important that the fiber has the mechanical strength sufficient for the practical use) the envelope diameter is from 50 to 100 μm. Such a fiber is able to transmit much wider band than the multimode fiber. It is quite understanable, that such small core diameter causes (still not quite solved) difficulties with the light "injection". The solution to this problem may lie in the self-focusing fiber, which after recent technological

improvements transmits the light pulses with a minimum of spreading, reaching single nano-seconds for kilometer of length.

It is enough to imagine, how small the fiber diameters are, to understand what difficulties lie in their production. The fiber must also satisfy very stringent requirements as far as material purity. Very small (for example 1:10^3) metal impurities cause significant increase in light absorption, changes in material density, small inhomogenouity or the air bubbles are the causes of dispersion which also significantly increases the damping (the weakening of the signal along the path). The light guide problems do not end on a fiber optics. Very important also are the light sources. Let us remember, that in the radio transmitters (from the long wave to the microwave) the real problem is the creation of electromagnetic vibration with defined and stable frequency. The light sources used in light guide lines should have at least similar properties. The almost ideal source became, as soon as it was discovered, and this discovery was one of the greatest in this century, the laser. Presently, other light sources are used, achieved through the great advances of solid state physics, such as semiconductor light emiting diodes. One can not say, however, that both mentioned problems are entirely solved, specifically, there is a lot remaining to be done in the area of light sources for long distance transmission lines.

Besides, there have always been plenty of technological problems; one has to modulate the light on the transmitting end, that is "fold in" the information by a change in certain characteristic qualities, and on the receiving end to extract this information from the light stream (we talk about the signal detection of course). Even to introduce the light flux into the fiber, with very small losses, creates considerable difficulties. The threshold of theoretical and practical knowledge (that is, technology)

which needs to be surmounted, is indeed very high in the case of light guides.

PRESENT APPLICATIONS...

They still do not include the telecommunication network for public use, although the work in this area has been conducted for some time. One could say, that so far, the light guides are useful only in "microtelecommunication", the signal transmission between separate systems, like computer centers, or other centers equipped with measurement and control apparatus, closed television networks, ship and submarines, aircraft and rockets. Their usefulness was proved in spatially small scale, but significant in other exploitation qualities.

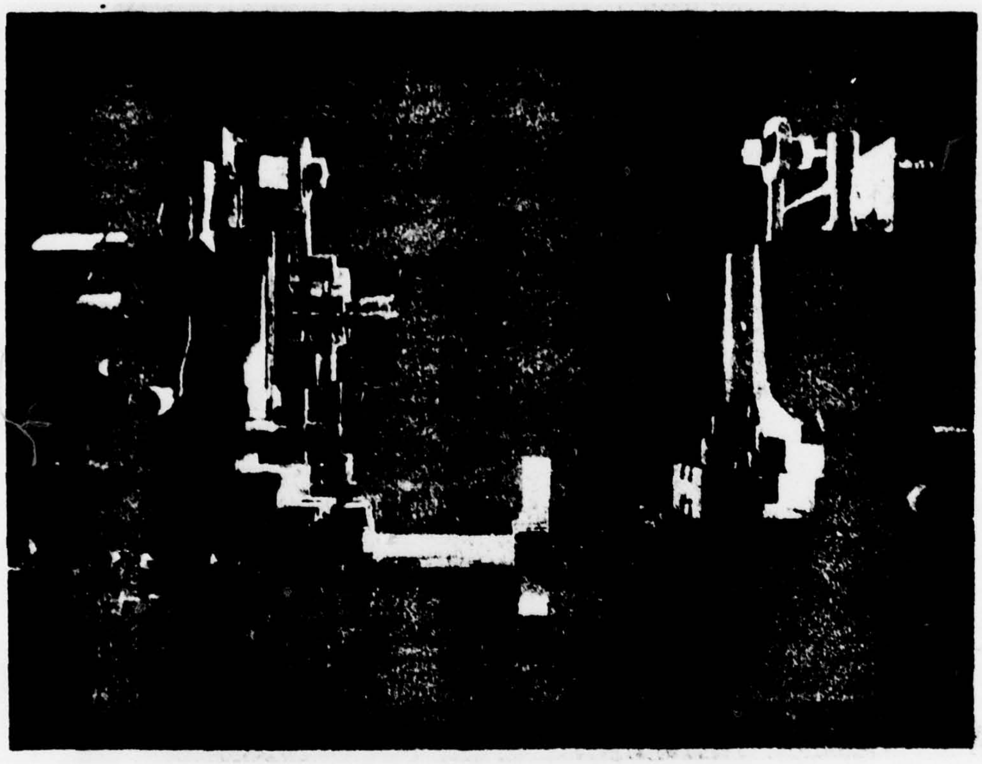
For many reasons the light guides in these kinds of applications are superior to the electrical signal lines. They are immune to interferences from other electromagnetic fields. Thus eliminated is the "number 1 problem" with which the engineers are encountered, when they have to place the lines carrying weak signals in proximity of radar installations, or high power radio transmitters, or among other similar lines. Moreover, there is nothing to spark in light guides, no short circuits (which may be especially dangerous in aircraft); there may be large potential differences between input and output, reaching thousands of volts. From the electrical standpoint it is significant that there is no receiver feedback, influence of cable impedance, reflections, etc., which usually requires great care in design and installation of electrical cables.

The light guides in addition, are much lighter than the electrical lines, due to the smaller diamters, and because there is no need for shielding (there is nothing to be induced). Thin glass fibers are elastic, easy to bend, vibration resistant, and breakage of one fiber does not cause the complete loss of connection. These advantages are especially important in installations where every gram is significant, where due to vibrations and overloading the onboard instrument working conditions are

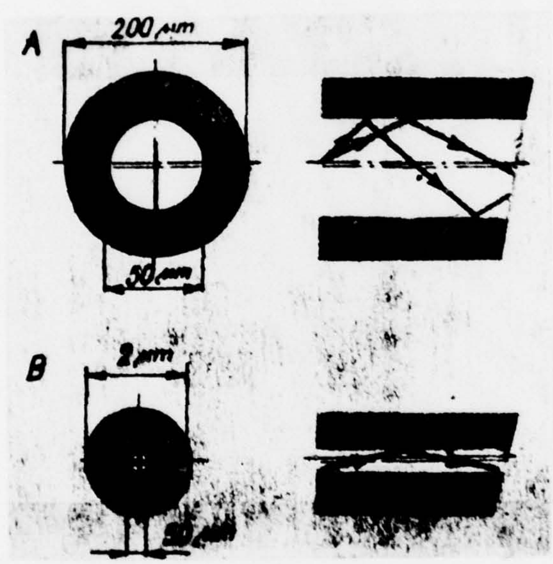
difficult, and reliability requirements are greater than anywhere: that is in aircraft and space vehicles.

. . . AND FUTURE PERSPECTIVES

From the calculations, it follows that the glass fibers may be used to transmit in one direction about 20,000 simultaneous telephone conversations. Because of practical reasons, one tries to use many independent fibers in a cable, but each of these fibers transmits much narrower bandwidth (about 20 MHz). The light guide cable of few milimeter diameter may contain several hundred optical fibers. As a result very wide cable transmission band creates the possibility of development of a new kind of wide band transmission systems. There we reach the boundary between predictions and dreams. Perhaps the light guide will be just this element which will be used in future multimillion metropolitan areas to create the information transmission network? All kinds of information: telephone, video, data. Even, as they say in diplomatic laguage, the "cautious optimism" permits to imagine a future home standard equipped (as present day houses are equipped with electricity, water and sewer) with few videophones, outlets for multichannel cable television, keyboard and display connected to a central computer and other terminals (for example to send a newspaper text). Perhaps even this will not exhaust the enormous possibilities of sending the information via lightguides, since just these enormous possibilities, both in the area of distributed information network in large and small metropolitan areas, and in long distance lines, will prove to be the impetus to create the new needs.



French experimental apparatus for fiber optics telecommunication.



Multimode fiber (A) and single mode (B). Proportions are not preserved in the figure.

The laser light injected into the hair-thin fiber (at the lens on left picture) travels along the fiber wrapped on a drum, and after travelling about 800 meters, illuminates the sheet of paper (right).

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